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Development of Prediction Models for Chemical Phosphorus Removal

Volume I

Research Report No. 68

search Program for the Abatement of Municipal Pollution
under Provisions of the Canada-Ontario Agreement
on Great Lakes Water Quality

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These RESEARCH REPORTS describe the results of investigations funded under the Research Program for the Abatement of Municipal Pollution within the provisions of the Canada-Ontario Agreement on Great Lakes Water Quality. They provide a central source of information on the studies being carried out in this program through in-house projects by both Fisheries and Environment Canada, and the Ontario Ministry of the Environment, and contracts with municipalities, research institutions and industrial organizations.

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DEVELOPMENT OF PREDICTION MODELS FOR CHEMICAL PHOSPHORUS REMOVAL

VOLUME I

by

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RESEARCH PROGRAM FOR THE ABATEMENT
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ABSTRACT

This project was initiated to establish a data bank of phosphorus removal treatability study results. The jar test and full scale treatability data were analyzed to obtain trends, cost data and other information that may prove beneficial in subsequent stages of the Canada-Ontario research program or similar programs. The accuracy of jar tests in predicting full scale chemical dosage requirements was assessed. Some simple and useful regression equations relating chemical dosage to wastewater phosphorus levels were derived. The effect of the Canadian requirements to limit the phosphorus content of laundry detergents on wastewater phosphorus levels (20% reduction) and on chemical phosphorus removal programs are also discussed.

RÉSUMÉ

L'objet des travaux était de créer une banque de données obtenues d'études de la déphosphatation. L'analyse des résultats d'expériences en laboratoire et en vraie grandeur a fourni des informations sur les tendances et les coûts, ainsi que d'autres renseignements qui pourront se révéler utiles au programme de recherche Canada-Ontario et à d'autres programmes analogues. Il a été déterminé avec quelle exactitude les essais en laboratoire laissaient prévoir les doses de produits chimiques requis pour le traitement en vraie grandeur. Il a aussi été discuté de l'effet de la réglementation canadienne de la teneur en phosphates dans les détersifs à lessive sur la concentration de phosphates dans les eaux résiduaires (réduction de 20%) et sur la déphosphatation chimique de ces dernières.

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CONCLUSIONS

An analysis of data from the Canada-Ontario phosphorus removal treatability program, collected over a four-year period (1971 to 1975) led to the following conclusions:

(i) For iron and aluminum salt addition the mean dosage from jar test results can be used to give an initial prediction of full scale average chemical requirements.

(ii) Regression relationships relating alum and iron chemical requirements to wastewater phosphorus levels were derived and can be used to reduce the scope of the jar test phase of future treatability studies.

(iii) On a province-wide basis, ferric chloride addition to the mixed liquor in a secondary wastewater treatment plant has proven to be the optimum method of meeting an effluent phosphorus requirement of 1 mg/l.

(iv) Of the 45 full scale phosphorus removal systems examined, 22 of the plants used iron salts, 20 used alum, and 3 used lime.

(v) As a result of the Canadian requirements to limit the phosphorus content of laundry detergents, raw municipal wastewater phosphorus levels have been reduced by approximately 20%. This phosphorus decrease resulted in significant reductions in the alum or iron dosages required for phosphorus removal (i.e., up to 44% for additions to raw wastewater and up to 46% for additions to mixed liquor).

1 INTRODUCTION

1.1 Background

It has been demonstrated that the removal of phosphorus from wastewater effluents is a feasible and cost effective method of reducing phosphorus discharge to water bodies. Chemical precipitation of phosphorus compounds by the use of lime, iron or aluminum salts is the most popular and economical method of achieving consistent phosphorus removals (Black and Veach, 1971).

The implementation of the Canada-Ontario Agreement on Great Lakes Water Quality (Prince and Bruce, 1972) stipulated that phosphorus be removed at all municipal wastewater treatment plants in the Lake Erie watershed by 1974, and in the Lake Ontario watershed by 1976. Over 200 treatment facilities were involved in this program. More specifically, plants located in the Upper Great Lakes and the Ontario region of the Ottawa River watershed were required to remove 80% of the phosphorus that entered the treatment facility, while an effluent total phosphorus concentration of 1 mg/l or less, 80% of the time, was required for all plants which discharged directly or indirectly to the St. Clair River, Lake St. Clair, the Detroit River, Lake Erie, the Niagara River, Lake Ontario and the Ontario section of the St. Lawrence River (Van Fleet, 1973). Figure 1 shows the regions and compliance schedules within the Province of Ontario.

A two-phase treatability study approach, administered by the Ontario Ministry of the Environment and financed under the Canada-Ontario Agreement, has been an integral part of the overall phosphorus removal program (MOE, 1972). To determine the optimum chemical (aluminum sulphate, iron salt or lime) dosage for each municipal treatment plant, the following treatability studies were required:

(i) preliminary jar testing to establish the prime precipitant that will achieve the degree of phosphorus removal required. An interim report on this phase is submitted for joint provincial and federal review; and

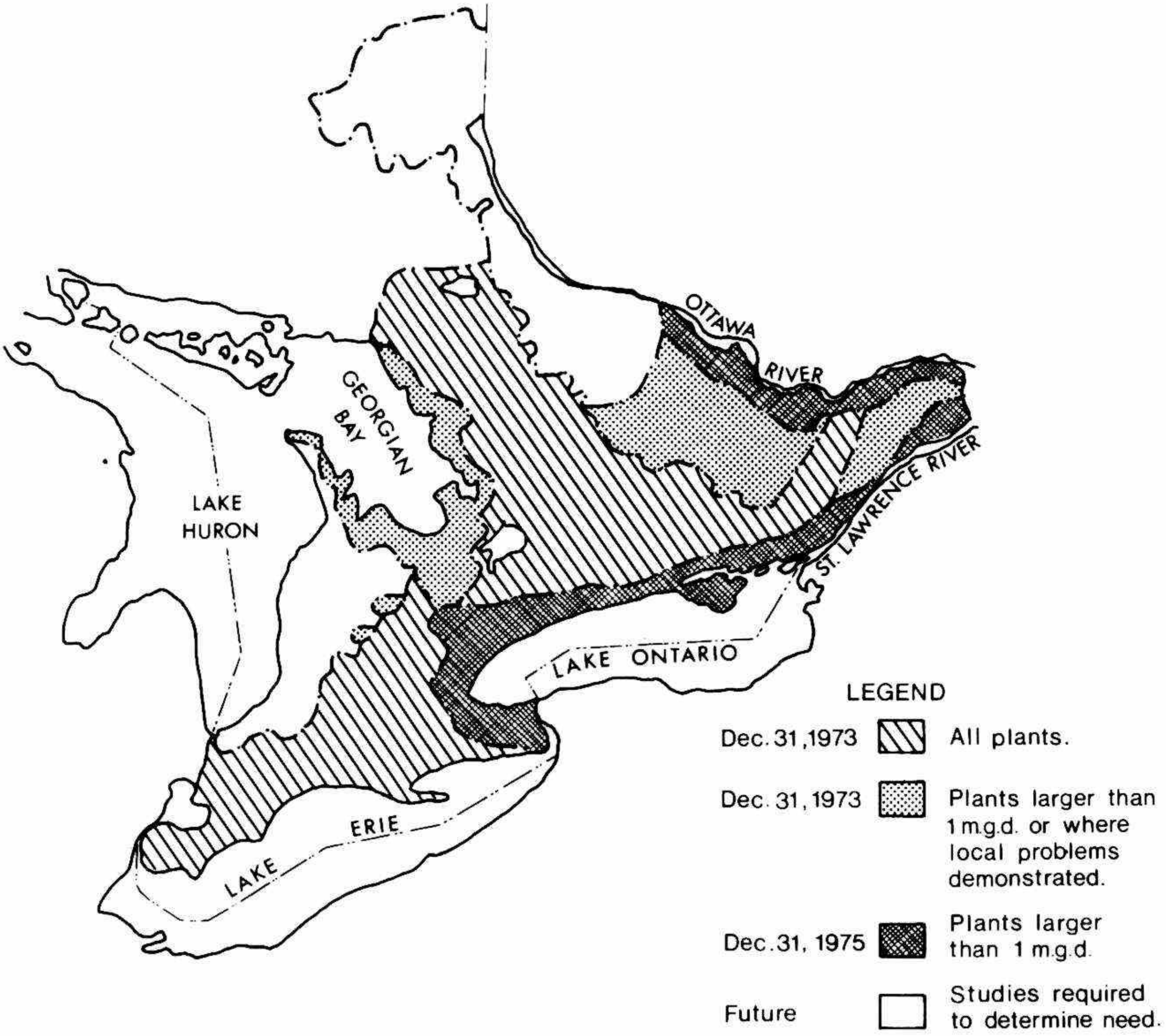
GEORGIAN BAY
OTTAWA RIVER
LAKE HURON
ST. LAWRENCE RIVER
LAKE ONTARIO
LAKE ERIE
LEGEND
Dec. 31,1973 ▧ All plants.
Dec. 31, 1973 ░ Plants larger than 1 m.g.d. or where local problems demonstrated.
Dec. 31, 1975 ▓ Plants larger than 1 m.g.d.
Future ☐ Studies required to determine need.

Fig.1 PROVINCE OF ONTARIO - SOUTHERN SECTION PHOSPHORUS REMOVAL PROGRAM SCHEDULED COMPLIANCE DATES. (Van Fleet, 1973)

(ii) once the jar test recommendations have been evaluated and approved, full scale testing with the prime precipitant is conducted for a period of six to eight weeks at each treatment plant. When these full scale studies are completed, a treatability study report is prepared containing recommendations for the permanent full scale phosphorus removal system.

Detailed guidelines for the jar test and full scale phases of the treatability program have been published by the Ministry of the Environment (MOE, 1972).

1.2 Objectives

Since the initiation of the treatability program in 1972, engineering consultants, the Ontario Ministry of the Environment and Fisheries and Environment Canada have collected a great deal of jar test and full scale phosphorus removal data. Accordingly, in 1973, a project with the following objectives was initiated:

(i) establish a standard format data bank of treatability study results with continuous updating as additional data becomes available; and

(ii) statistically analyze and interpret the jar test and full scale treatability data in order to obtain trends and cost data;

(iii) develop some simple regression equations relating chemical dosage requirements to initial phosphorus levels.

In a related study conducted in conjunction with this project, some more detailed models for predicting phosphorus removal requirements on the basis of several common wastewater characteristics are under development (Prested et al, 1977).

2 METHODOLOGY

2.1 Establishing the Data Bank

As pointed out previously, data from the jar testing and full scale phases of the treatability program are contained in interim reports submitted for review on each phase. The first step of this project involved the extraction of the relevant data from these reports and its organization into a standard format for data processing.

Figure 2 shows the locations of plants where jar tests and full scale treatability studies were conducted.

The jar test data were collected in accordance with the Ministry of the Environment guidelines (Appendix A). Tests with lime, aluminum sulphate and ferric chloride were carried out on the plant raw wastewater to simulate primary phosphorus precipitation conditions, and on secondary effluent (if applicable) with alum and ferric chloride to simulate removal conditions where the chemical is added to the mixed liquor. The jar test reports included information on chemical dosage, initial total phosphorus, residual total phosphorus, mixing conditions, visual floc observations and other related data. An example of jar test data arranged in the standard format is shown in Table 1.

Full scale phosphorus removal treatability studies were carried out in accordance with the guidelines shown in Appendix A. The full scale phase was designed to demonstrate that phosphorus removal, using the prime precipitant identified by the jar tests, was compatible with the existing treatment plant. The information presented in the final treatability report included total phosphorus, soluble phosphorus, BOD_5, pH and suspended solids data in the plant influent and effluent. Plant operational parameters (e.g., dissolved oxygen in aeration tanks, sludge volume index, sludge return rates, etc.) were noted in a few reports. An example of full scale data arranged in the standard format is shown in Table 2.

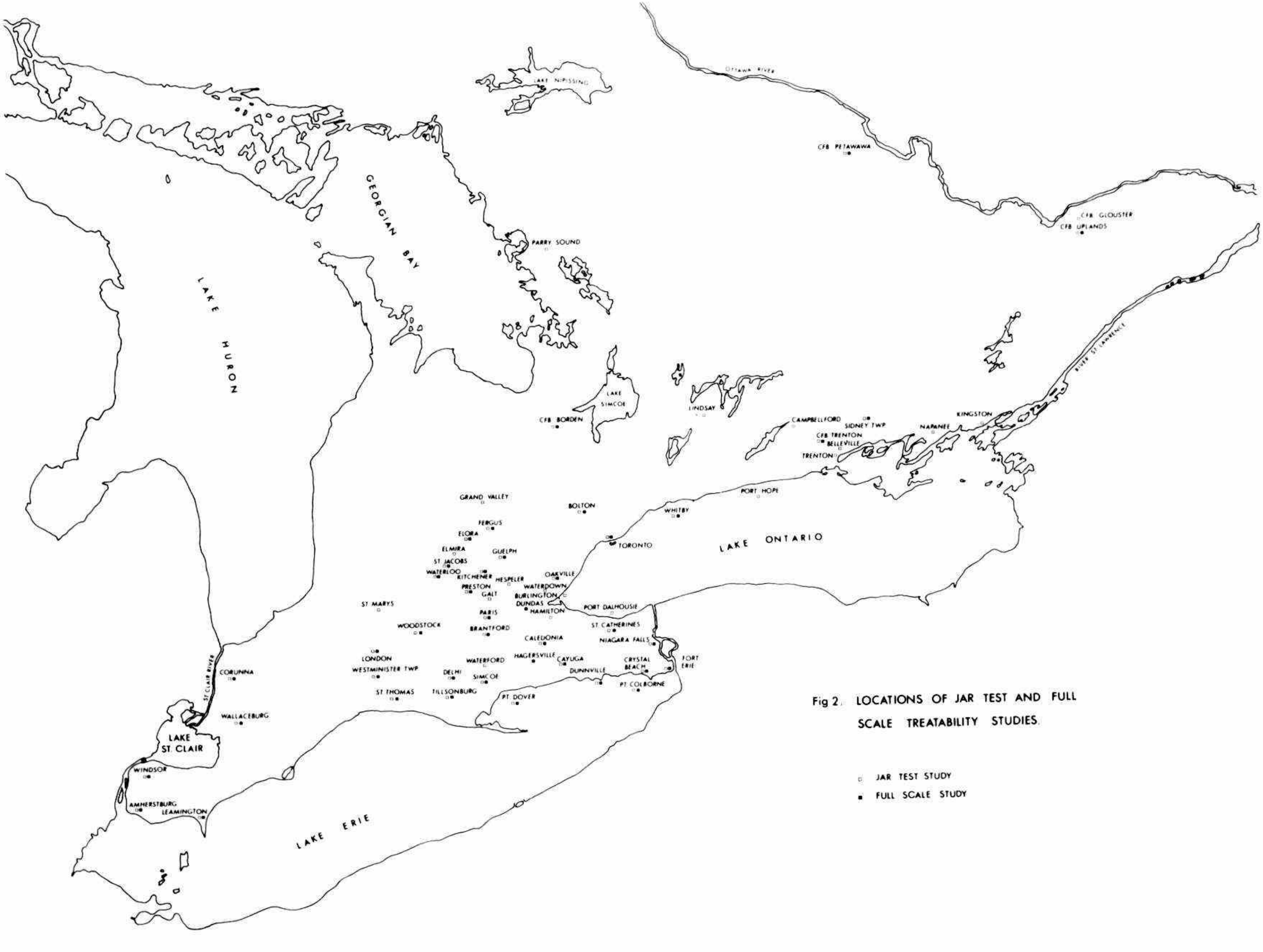

Fig 2. LOCATIONS OF JAR TEST AND FULL SCALE TREATABILITY STUDIES.

TABLE 1 AN EXAMPLE OF JAR TEST DATA ARRANGED IN STANDARD DATA FORMAT

STUDY	RUN	TYPE	INITIAL PHOSPHORUS*	CONTROL PHOSPHORUS*†	CHEMICAL	DOSAGE	RESIDUAL PHOSPHORUS*
15	1	R	3.70	2.60	A	0.00	2.60
15	1	R	3.70	2.60	A	4.54	0.80
15	1	R	3.70	2.60	A	9.08	0.32
15	1	R	3.70	2.60	A	13.62	0.26
15	1	R	3.70	2.60	A	18.16	0.34
15	2	R	1.80	1.80	A	0.00	1.80
15	2	R	1.80	1.80	A	2.27	1.00
15	2	R	1.80	1.80	A	4.54	0.92
15	2	R	1.80	1.80	A	9.08	0.46
15	3	R	1.30	1.10	A	0.00	1.10
15	3	R	1.30	1.10	A	2.27	1.10
15	3	R	1.30	1.10	A	4.54	0.84
15	4	R	5.70	5.20	A	0.00	5.20
15	4	R	5.70	5.20	A	4.54	4.50
15	4	R	5.70	5.20	A	9.08	1.00
15	5	R	2.80	3.20	A	0.00	3.20
15	5	R	2.80	3.20	A	2.27	2.00
15	5	R	2.80	3.20	A	4.54	1.20
15	5	R	2.80	3.20	A	9.08	0.56
15	6	R	5.80	5.40	A	0.00	5.40
15	6	R	5.80	5.40	A	2.27	4.80
15	6	R	5.80	5.40	A	9.08	1.50
15	7	R	3.10	2.80	A	0.00	2.80
15	7	R	3.10	2.80	A	2.27	2.00
15	7	R	3.10	2.80	A	4.54	1.30
15	7	R	3.10	2.80	A	9.08	0.56
15	8	R	11.00	11.00	A	0.00	11.00
15	8	R	11.00	11.00	A	2.27	11.00
15	8	R	11.00	11.00	A	4.54	10.00
15	9	R	3.40	3.20	A	0.00	3.20
15	9	R	3.40	3.20	A	2.27	2.30
15	9	R	3.40	3.20	A	4.54	1.60
15	10	R	5.00	4.60	A	0.00	4.60
15	10	R	5.00	4.60	A	4.54	3.40
15	10	R	5.00	4.60	A	9.08	1.00
15	11	R	6.60	6.20	A	0.00	6.20
15	11	R	6.60	6.20	A	2.27	6.00
15	11	R	6.60	6.20	A	4.54	5.00
15	11	R	6.60	6.20	A	9.08	2.90

R = Addition to raw wastewater.
A = Alum.

*Phosphorus concentrations as Total P.
†Control phosphorus (no chemical addition, but mixed on jar tester).
All concentrations in mg/l.

TABLE 2 AN EXAMPLE OF FULL SCALE TREATABILITY STUDY DATA ARRANGED IN STANDARD DATA FORMAT

STUDY	RUN	PT OF ADD	CHEM	DOSE	OTHR CHEM	DOSE	FLOW	INFL TOT P	INFL SOL P	INFL ORT P	INFL BOD	INFL SS	INFL pH	EFFL TOT P	EFFL SOL P	EFFL ORT P	EFFL BOD	EFFL SS
06	1	M	A	9.5	N	N	13.2	8.5	6.1	N	256	310	N	--	.2	N	17	15
06	2	M	A	9.6	N	N	13.5	8.2	5.7	N	247	260	N	.6	.3	N	--	11
06	3	M	A	9.4	N	N	20.2	8.4	6.1	N	--	430	N	.5	.2	N	--	29
06	4	M	A	9.4	N	N	13.1	13.6	8.4	N	189	290	N	1.0	.5	N	18	24
06	5	M	A	5.9	N	N	13.8	9.6	7.4	N	223	400	N	.8	.4	N	18	23
06	6	M	A	10.5	N	N	13.5	9.4	7.1	N	215	280	N	1.0	.5	N	15	17
06	7	M	A	9.4	N	N	13.5	9.3	7.4	N	253	270	N	1.0	.6	N	14	21
06	8	M	A	10.0	N	N	10.4	9.6	8.8	N	--	--	N	1.1	.8	N	--	--
06	9	M	A	9.3	N	N	13.1	9.5	7.1	N	--	290	N	1.2	.8	N	--	28
06	10	M	A	9.5	N	N	13.3	9.7	7.7	N	272	330	N	1.0	.7	N	12	21
06	11	M	A	8.9	N	N	13.1	8.6	6.8	N	226	310	N	1.0	.7	N	11	23
06	12	M	A	8.3	N	N	13.0	9.8	7.2	N	243.	300.	N	.9	.6	N	11	17
06	13	M	A	8.2	N	N	12.8	10.9	9.2	N	--	380	N	.7	.6	N	--	17
06	14	M	A	8.4	N	N	10.0	10.9	6.8	N	--	--	N	--	.6	N	--	--
06	15	M	A	9.5	N	N	12.5	7.8	7.8	N	--	--	N	1.2	.8	N	--	23
06	16	M	A	9.5	N	N	13.0	9.3	7.5	N	249	290	N	1.1	.7	N	13	15
06	17	M	A	8.8	N	N	12.8	9.4	7.9	N	293	300	N	1.1	.8	N	13	17
06	18	M	A	9.6	N	N	12.7	10.9	7.2	N	215	290	N	.7	.5	N	12	12
06	19	M	A	11.1	N	N	12.7	9.9	7.9	N	--	340	N	.8	.5	N	--	19
06	20	M	A	10.6	N	N	12.7	9.1	6.7	N	236	280	N	.8	.5	N	12	14
06	21	M	A	10.5	N	N	12.6	10.4	7.2	N	328	340	N	.8	.5	N	12	15
06	22	M	A	11.5	N	N	13.6	9.1	6.7	N	320	340	N	.7	.5	N	13	12
06	23	M	A	10.4	N	N	14.3	9.7	8.4	N	--	340	N	.7	--	N	--	17
06	24	M	A	7.1	N	N	16.13	8.3	5.6	N	--	310	N	1.2	.8	N	--	13
06	25	M	A	6.6	N	N	17.37	7.3	5.0	N	202	290	N	1.2	.7	N	24	15
06	26	M	A	5.0	N	N	16.85	8.0	5.4	N	264.	210.	N	.9	.6	N	17	15
06	27	M	A	5.5	N	N	15.16	8.7	6.1	N	--	230	N	1.2	.9	N	--	15
06	28	M	A	5.2	N	N	20.11	9.8	5.0	N	--	360	N	1.4	1.8	N	--	61
06	29	M	A	6.0	N	N	17.64	7.9	4.6	N	168	190	N	1.2	1.0	N	36	11
06	30	M	A	7.7	N	N	19.64	7.1	4.2	N	138	240	N	.7	1.3	N	47	54
06	31	M	A	7.6	N	N	18.30	8.2	7.3	N	--	250	N	1.0	.5	N	--	20
06	32	M	A	6.1	N	N	17.90	7.3	5.3	N	--	190	N	.9	.5	N	--	19
06	33	M	A	6.8	N	N	17.80	10.3	6.8	N	--	330	N	.4	.6	N	--	20
06	34	M	A	7.1	N	N	16.70	7.5	5.3	N	191	230	N	1.6	.6	N	21	19

M = Mixed liquor.
A = Alum.
N = None.
Flow = mgd.
All concentrations as mg/l.

2.2 Data Analyses

Data analysis and interpretation were included as part of each jar test and full scale treatability report. However, as the reports were prepared by various consultants or Ministry of the Environment personnel, direct comparison between studies were complicated. This was due to the use of varying data analyses procedures. (As an example, some reports contained log probability plots, whereas others contained arithmetic probability plots.) As a result, Fortran IV programs were written to perform the following standard data analyses on the jar test data:

(i) generation and plotting of log probability plots of "residual total phosphorus versus probability of occurrence" for various chemical dosages (an example is shown in Figure 3); and,

(ii) calculation of basic statistics (i.e., means, standard deviation and inter-variable correlations); a plot of influent and effluent total and soluble phosphorus levels over the duration of the full scale study. An example for soluble phosphorus is shown in Figure 4.

The jar test and full scale data and data analyses for all studies received were compiled and are on file at the Wastewater Technology Centre.

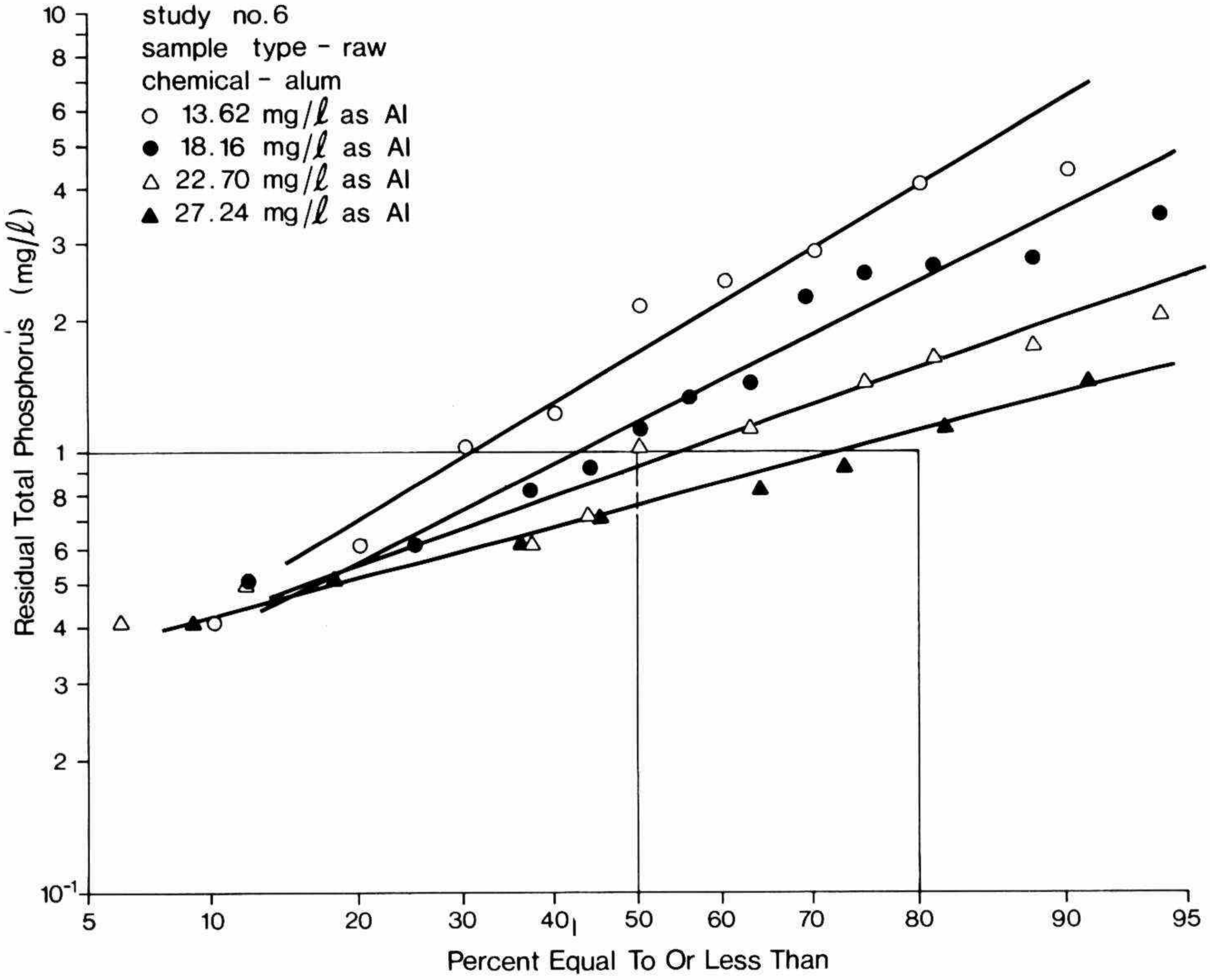

Fig. 3 PROBABILITY PLOT FOR KITCHENER JAR TEST TREATABILITY DATA

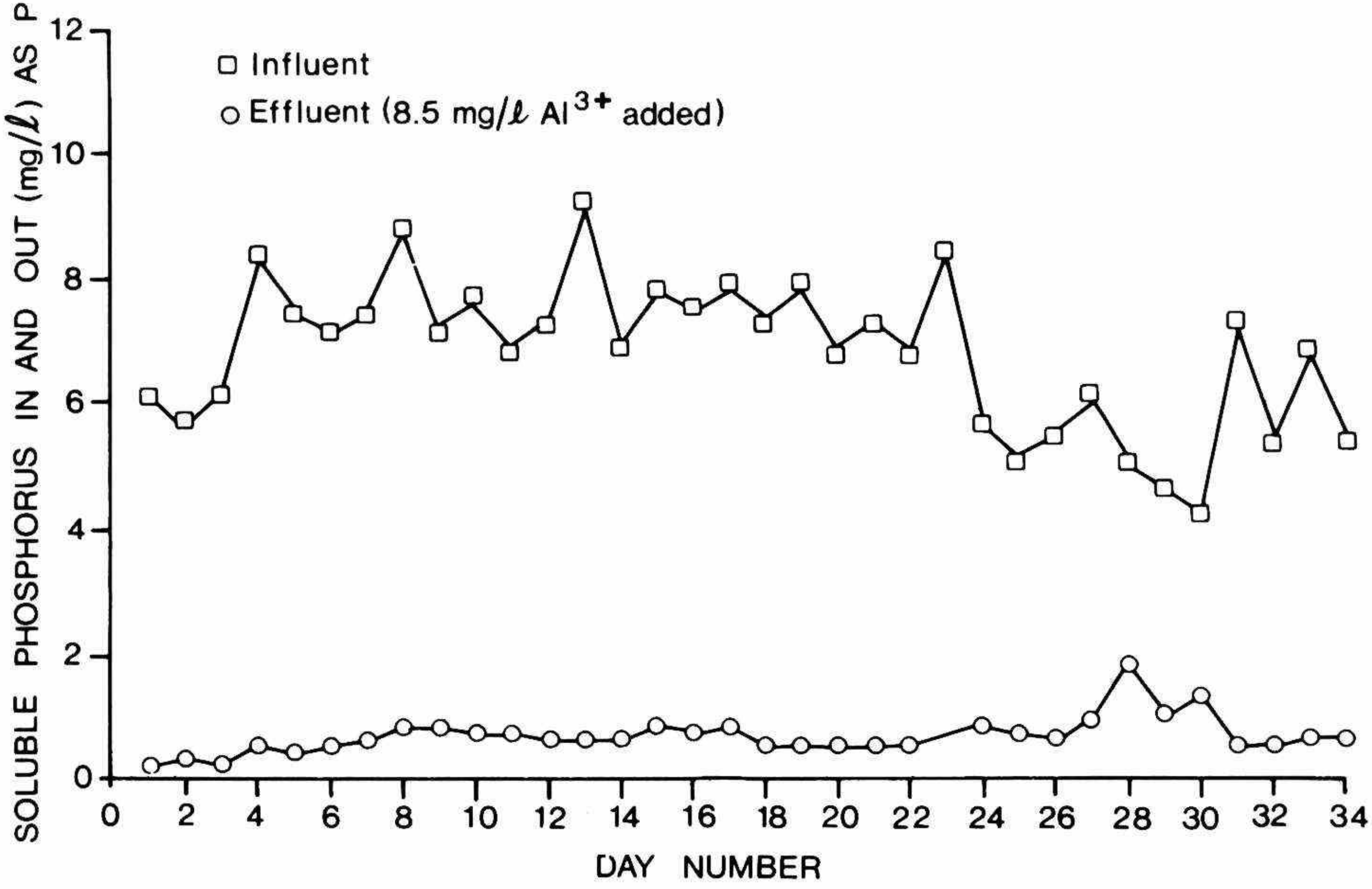

Fig.4 INFLUENT AND EFFLUENT SOLUBLE PHOSPHORUS LEVELS FOR THE FULL SCALE TREATABILITY STUDY AT KITCHENER.

3 DISCUSSION

3.1 Impact of Laundry Detergent Reformulation

The treatability program commenced in 1971 and was completed in 1975. However, in 1971, under regulations of the Canada Water Act, P_2O_5 content was restricted to less than 20%, and as of January, 1973, further restricted to less than 5%. Thus, during the treatability program the phosphorus content of Canadian laundry detergents changed significantly. Consequently, a significant reduction in wastewater total phosphorus levels occurred during this period (Table 3). Assuming that the pre-1973 and post-1973 wastewaters are comparable, the influent total phosphorus concentration decreased from approximately 7.1 mg/l to 5.7 mg/l. This represents a 20% reduction in wastewater phosphorus loading directly attributable to laundry detergent reformulation. This is in agreement with the full scale laundry detergent substitution results obtained by Shannon and Kamp (1973). As shown in Table 3, a proportional reduction (24%) in effluent total phosphorus (discharge to the receiving water) was also achieved.

Comparing jar test data collected prior to and after the detergent reformulation indicates that this reduction in wastewater phosphorus levels has also resulted in a reduction in the alum or ferric chloride dosages required to achieve a 1 mg/l effluent total phosphorus level. This trend is evident in Table 4. For chemical addition to raw wastewater, the overall effect has been to decrease alum and ferric chloride requirements by 32% and 44%, respectively. Similarly, chemical addition to the mixed liquor resulted in a 41% decrease in alum requirements and 46% in ferric chloride. Unfortunately, an insufficient number of full scale studies were conducted prior to 1973 to make a comparison on a full scale plant basis.

3.2 Relationship Between Influent Phosphorus and Chemical Requirements

As pointed out in the previous section, a reduction in raw wastewater phosphorus levels by detergent reformulation resulted in

TABLE 3 IMPACT OF DETERGENT REFORMULATION ON WASTEWATER PHOSPHORUS LEVELS

	Before Reformulation Prior to Jan. 1973*	After Reformulation 1973 to date*	Percent Reduction
Raw Wastewater Total Phosphorus (mg/l as P)	7.1 (n = 38)	5.7 (n = 35)	20%
Secondary Effluent Total Phosphorus (mg/l as P)	4.5 (n = 31)	3.4 (n = 25)	24%

n = Number of Observations.
* Average value.

TABLE 4 AVERAGE JAR TEST DOSAGES OF ALUM OR FERRIC CHLORIDE REQUIRED TO ACHIEVE A 1 MG/L TOTAL PHOSPHORUS RESIDUAL PRIOR TO 1973 AND AFTER 1973

Chemical	Raw Wastewater Addition			Mixed Liquor Addition		
	Pre-1973	1973-date	Reduction	Pre-1973	1973-date	Reduction
Ferric Chloride (mg/l as Fe^{3+})	30.5 (n = 37)	17.2 (n = 36)	44%	21.5 (n = 31)	12.8 (n = 26)	41%
Alum (mg/l as Al^{3+})	19.4 (n = 38)	13.1 (n = 36)	32%	12.8 (n = 31)	6.9 (n = 27)	46%

lower chemical requirements to achieve a 1 mg/l effluent phosphorus concentration. This positive relationship between influent phosphorus and chemical requirement has been noted by several other researchers. For example, Shannon and Kamp (1973) and Shannon and Rush (1973) developed regression equations from data at a few Canadian Forces Bases to describe the relationship between influent phosphorus concentration and alum and ferric chloride dosages to achieve 1 mg/l effluent phosphorus. A good relationship was identified for estimating alum dosage; however, no strong relationship could be found for ferric chloride because of the limited amount of data available.

As in any statistical analysis, more reliable results are obtained when a large data base is used. It was hoped that by analysing all the data collected during the Canada-Ontario treatability study program, relationships between influent phosphorus and chemical requirements could be developed that would be sufficiently reliable for preliminary scale-up or design purposes.

A summary of jar test and full scale results for 86 municipalities (to April, 1975) is presented in Appendix B. Plant type, jar test, initial total phosphorus (TP), jar test chemical dosages, average full scale influent and effluent total phosphorus and chemical dosages, point of chemical addition and average clarifier overflow rates are shown where available. To date, 45 full scale studies have been completed.

For statistical analysis, the raw data from Appendix B were grouped according to type of chemical (ferric chloride or alum) and point of addition (to the raw wastewater or to the mixed liquor). In the jar test studies, the chemical dosage reported is that required to give a 1 mg/l effluent phosphorus concentration 80% of the time. However, it must be realized in using the full scale study data that the chemical dosage reported in Appendix B rarely achieved an average effluent total phosphorus of exactly 1 mg/l, but was generally within ±0.5 mg/l of the 1 mg/l standard.

Data from all plants were used in analysing results of addition to the raw wastewater. Analysis of conventional activated sludge (CAS) plant data alone did not significantly change the regression equations or the average phosphorus and chemical values obtained when all biological plant data was combined. Therefore, for addition to the mixed liquor, data from all biological plants were used in the statistical analysis.

Results of the statistical analyses of each group of data are summarized in Table 5. The correlation coefficients (r) for all six linear regression equations developed were determined to be statistically significant at the 95% confidence level.

From the regression equations and average chemical/phosphorus ratios presented in Table 5, two trends are evident:

(i) Less chemical was required (i.e., lower Al^{3+}/TP or Fe^{3+}/TP ratio) when chemical was added to the mixed liquor rather than to the raw wastewater. The one anomaly was in the jar test addition of ferric chloride to the mixed liquor which predicted a slightly higher dosage requirement than the jar test ferric chloride to the raw wastewater equation.

(ii) The equations developed from jar test data predicted a higher chemical requirement than did the equations from full scale data. This was partly because the jar test dosages were those to give 1 mg/l effluent phosphorus 80% of the time, whereas the full scale dosages were averages that gave average effluent phosphorus of approximately 1 mg/l (i.e., 0.9 mg/l for iron addition; 1.2 mg/l for alum addition). However, the lower chemical requirement in full scale plants may also reflect the benefit obtained from sludge recycle in a full scale plant. The relationship between jar test predictions and full scale dosage requirements is discussed further in the next section.

Overall, the equations were capable of predicting chemical dosages for a particular wastewater to within ±30%. The implication of this is that in future treatability programs it may be possible to eliminate or reduce the scope of the jar testing phase. For example,

TABLE 5 REGRESSION RELATIONSHIPS BETWEEN CHEMICAL REQUIREMENTS AND INFLUENT WASTEWATER PHOSPHORUS LEVELS

Chemical	Jar Test Data**		Full Scale Data**	
	Raw Wastewater Addition	Mixed Liquor Addition	Raw Wastewater Addition	Mixed Liquor Addition
Iron* (mg/l as Fe^{3+})	Fe^{3+} = 2.8+3.3(TP) r = .653 n = 71 Ave Fe^{3+} = 24.3 Ave TP = 6.5 Ave Fe^{3+}/TP = 3.7	Fe^{3+} = 2.4+3.8(TP) r = .650 n = 57 Ave Fe^{3+} = 17.8 Ave TP = 4.0 Ave Fe^{3+}/TP = 4.5	Insufficient data for regression n = 7 Ave Fe^{3+} = 16.0 Ave TP = 5.3 Ave Fe^{3+}/TP = 3.0	Fe^{3+} = .5+1.4(TP) r = .689 n = 15 Ave Fe^{3+} = 9.2 Ave TP = 6.0 Ave Fe^{3+}/TP = 1.5 Ave Residual TP = .9
Alum (mg/l as Al^{3+})	Al^{3+} = .6+2.4(TP) r = .689 n = 72 Ave Al^{3+} = 16.2 Ave TP = 6.5 Ave Al^{3+}/TP = 2.5	Al^{3+} = 1.5+2.2(TP) r = .553 n = 57 Ave Al^{3+} = 10.4 Ave TP = 4.0 Ave Al^{3+}/TP = 1.6	Insufficient data for regression n = 5 Ave Al^{3+} = 10.3 Ave TP = 6.2 Ave Al^{3+}/TP = 1.7	Al^{3+} = -.3+1.3(TP) r = .642 n = 15 Ave Al^{3+} = 7.2 Ave TP = 5.7 Ave Al^{3+}/TP = 1.3 Ave Residual TP = 1.2

* Iron was added as $FeCl_3$ except at two plants where pickle liquor was used.

** To achieve 1 mg/l TP.

TP = Average Total Phosphorus (mg/l as P) in the raw wastewater when chemical added to raw wastewater.
= Average Total Phosphorus (mg/l as P) in the secondary when chemical added to mixed liquor.

r = Correlation coefficient (the r's for all equations are significant at the 95% confidence level).

n = Number of observations.

** To achieve 1 mg/l TP.

the simple linear regression equations or the chemical to phosphorus ratios, presented herein, could be used to estimate chemical (alum or iron) dosages. The full scale phase of the treatability program may then be carried out to optimize the chemical dosage, establish the optimum point of addition and estimate sludge production and other impacts on plant operation due to the chemical additions.

3.3 Relationship Between Jar Test Predictions and Full Scale Performance

The relationship between jar test predictions and full scale performance was investigated for studies adding iron and alum to the mixed liquor. Derivation of jar test to full scale ratios is shown in Appendix C. For the 27 studies adding alum or ferric chloride to the mixed liquor, the ratio of jar test dosage required to achieve 1 mg/l phosphorus 80% of the time to the actual full scale dosage required to achieve an average effluent phosphorus of approximately 1 mg/l was 1.63:1. In other words, jar test predictions tended to overestimate full scale requirements by 63%. This was to be expected since the jar test 80% probability was being compared to the average full scale value. However, comparing the 50% value from the jar test results to the full scale average dosage resulted in a more reasonable ratio of 1.15:1 (that is, the jar tests slightly overestimated full scale requirements). This relationship is depicted graphically in Figure 5.

Analysed separately, the jar test to full scale ratio for iron dosage, was 1.24:1. The same ratio for alum dosage was 1.06:1.

Overall, the jar testing program was successful in delineating the prime coagulant and estimating the full scale dosage to within ±25%. This was just slightly better than the accuracy of the regression equations discussed in the previous section.

3.4 Cost and Performance of Full Scale Phosphorus Removal Systems

Some of the basic statistics from the Canada-Ontario full scale treatability study program are presented in Table 6. In reference to this table, it should be noted that data from study number 27

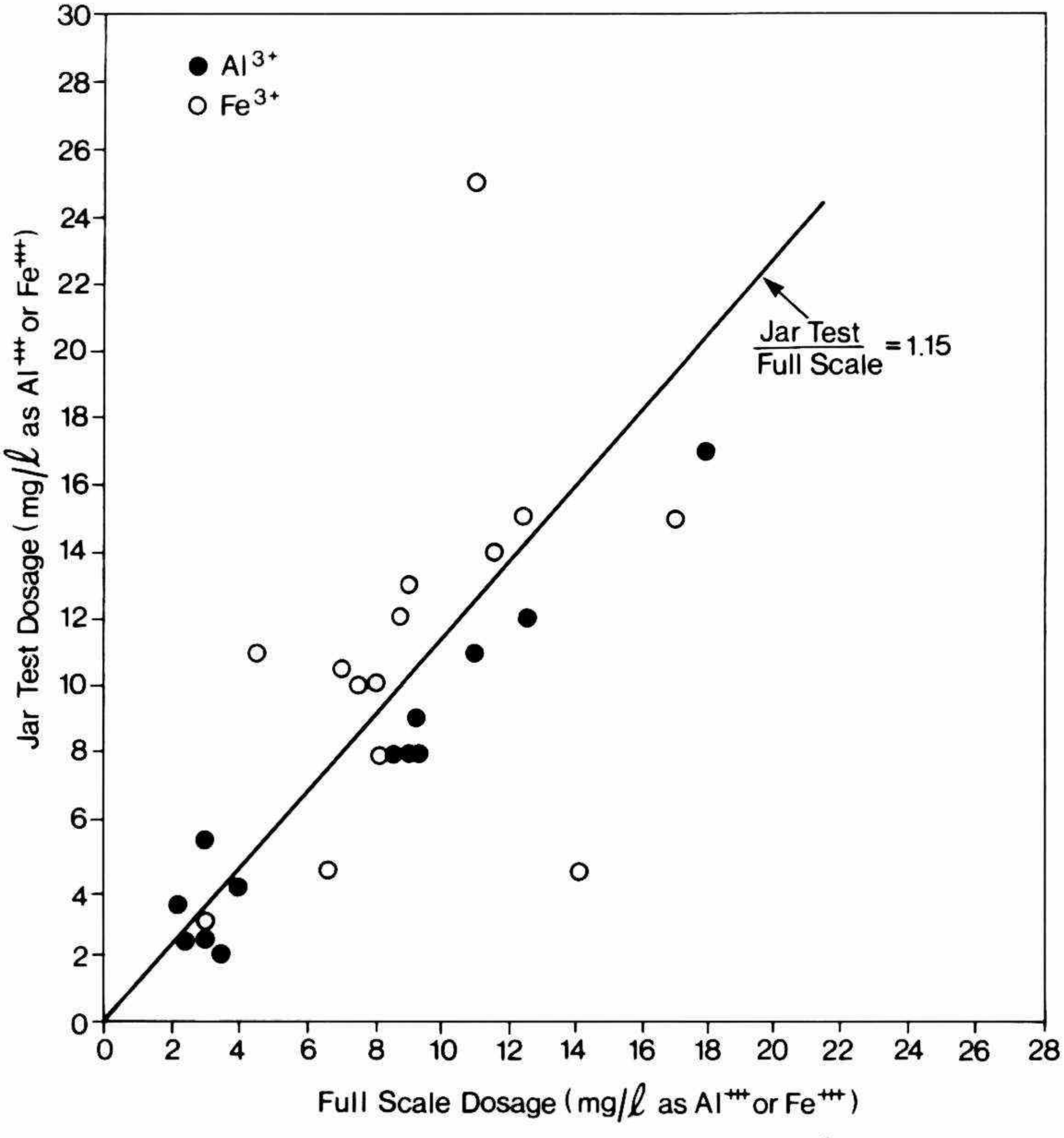

Fig. 5 COMPARISON OF JAR TEST DOSAGES (for 1 mg/ℓ P 50 % of the time) TO FULL SCALE DOSAGES (for 1 mg/ℓ P average) AT PLANTS ADDING ALUM OR FERRIC CHLORIDE TO THE MIXED LIQUOR.

TABLE 6 BASIC STATISTICS FROM THE CANADA-ONTARIO FULL SCALE TREATABILITY STUDY PROGRAM

Chemical	Total No. of Plants	Addition to Raw Wastewater			Addition to Mixed Liquor		
		Number of Plants	Avg. Dose (mg/l)	Avg. Cost[3] ($/million gallons)	Number of Plants	Avg. Dose (mg/l)	Avg. Cost[3] ($/million gallons)
Iron	22	7	16.0[1]	26.9	15	9.2	15.0
Alum	20	5	10.3[1]	33.5	15	7.2	21.7
Lime	3	3	118[2]	25.5	-	-	-

[1] - Dosages as mg/l Fe/Al.

[2] - Dosages as mg/l Ca.

[3] - Chemical cost only (Dec. 1974, from consultants).

(Table B-1) were not used since ferric chloride and lime were added together. Also, two sets of data from study number 17 (Table B-1) were used (i.e., ferric chloride to the mixed liquor and pickle liquor to the mixed liquor).

The optimum method for phosphorus removal in most instances involved the addition of ferric chloride or alum to the mixed liquor (i.e., 30 out of 45 plants). Of the 12 plants that tested full scale addition of alum or ferric chloride to the raw wastewater, seven were primary plants and had no other option. Only three plants tested lime addition.

The chemical cost for phosphorus removal based on the average full scale chemical dosage, wastewater flow and actual delivered chemical cost (December, 1974 prices), were calculated by the consultants for each full scale study. Where the average effluent phosphorus levels achieved were less than 1 mg/l, the cost indicated would obviously be lower to meet the 1 mg/l requirement. These situations are identified in Table B-1 of Appendix B by a minus sign. The opposite situation (i.e., an effluent total phosphorus average of 1 mg/l was not met during the full scale additions) is denoted by a plus sign accompanying the cost figure. On the basis of the average chemical costs, ferric chloride addition to the mixed liquor was the most economical method of meeting an effluent phosphorus concentration of 1 mg/l when working with an existing secondary plant. However, it must be realized that delivered chemical costs will influence each particular situation and that the data presented here are for a geographically diverse group of Ontario municipalities.

Boyko and Rupke (1973) observed that if secondary clarifier overflow rates exceeded 31.8 to 34.2 $m^3/m^2 \cdot day$ (650 to 700 $Igpd/ft^2$) in phosphorus removal systems, significant deterioration of effluent quality (with respect to suspended solids and total phosphorus) occurred. Of the 45 plants reported here, only eight had clarifier overflow rates in excess of this critical level. However, there was no clear trend among these plants which would indicate that effluent quality had deteriorated significantly (e.g., the Port Colborne plant

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achieved an average effluent total phosphorus level of 0.6 mg/l when the average overflow rate was 46.0 $m^3/m^2 \cdot day$ (940 Igpd/ft^2)). Figure 6 clearly illustrates the lack of correlation between clarifier overflow rate and effluent total phosphorus concentration at conventional activated sludge (CAS), extended aeration (EA) and primary (P) plants with chemical addition to the raw wastewater (R), or to the mixed liquor (M).

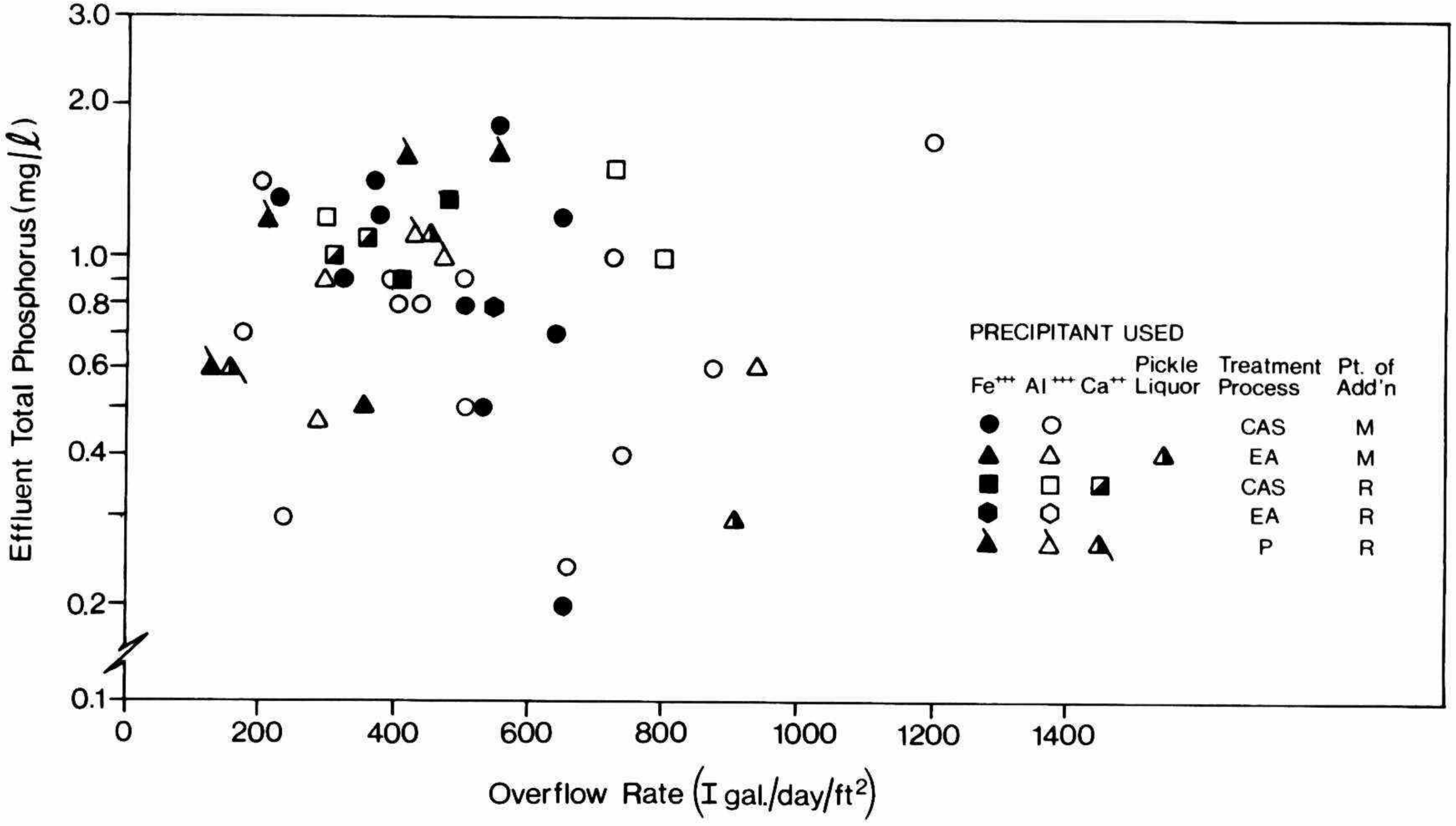

Fig.6 EFFLUENT TOTAL PHOSPHORUS CONCENTRATIONS VERSUS CLARIFIER OVERFLOW RATE

APPENDIX A

GUIDELINES FOR CONDUCTING TREATABILITY STUDIES FOR PHOSPHORUS REMOVAL AT WASTEWATER TREATMENT PLANTS

GUIDELINES FOR CONDUCTING TREATABILITY STUDIES FOR PHOSPHORUS REMOVAL AT WASTEWATER TREATMENT PLANTS

An information brief for consulting engineers and municipal officials and a supplement to Guidelines for Initiating Treatability Studies. Further information can be obtained by contacting Mr. J.W.G. Rupke or Mr. G.L. Van Fleet.

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135 St. Clair Avenue West
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TORONTO, Ontario
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28 April, 1972

GUIDELINES FOR CONDUCTING TREATABILITY STUDIES FOR PHOSPHORUS REMOVAL AT WASTEWATER TREATMENT PLANTS

INTRODUCTION

Nutrients are known to play a significant role in the growth and proliferation of algae in the aquatic environment. The control of specific nutrient inputs, such as phosphorus, can aid in correcting existing eutrophication problems and protect our waterways from over abundant algal production.

The Province of Ontario is presently involved in a five-year program to control, by 1975, phosphorus discharges from more than two hundred existing wastewater treatment plants serving some 4.7 million persons. Permanent phosphorus removal facilities must be operational by December 31, 1973, in the most critically affected areas of the Province; by December 31, 1975, for those discharging to waters deemed to be in a less critical condition; and three years after notification in all other areas of the Province where problems are found to exist or where protective measures are required. Figure 1, shown earlier, outlines the areas of the Province affected by the program and the respective compliance dates. The program is a response to International Joint Commission recommendations on the Lower Great Lakes and the demonstrated need for nutrient controls in prime recreational waters throughout the Province.

Affected wastewater treatment plants located in the Upper Great Lakes and Ottawa River Systems are required to remove 80% of the phosphorus from sewage which enters the treatment plant. An average effluent total phosphorus concentration of 1 mg/l is required at all affected plants which discharge directly or indirectly to the St. Clair River, Lake St. Clair, the Detroit River, Lake Erie, the Niagara River, Lake Ontario and the Ontario section of the St. Lawrence River. The permanent facilities and prime chemical coagulant selected must, in each case, be capable of greater removal efficiencies, as further receiving water studies may dictate the need for more stringent requirements.

GUIDELINE OBJECTIVES

These guidelines are designed to assist personnel involved in carrying out phosphorus removal treatability studies in determining the most efficient and economical means to implement phosphorus removal through chemical addition at existing wastewater treatment plants. The methodology, which includes both jar testing and pilot study phases, would allow the prediction of the prime coagulant best suited for phosphorus removal at any particular treatment facility and a determination of whether the chemical used would have any effect on the existing wastewater treatment process, facilities, method of sludge treatment, and subsequent sludge disposal practices. The choice of chemical would be limited to the process most compatible with sewage characteristics and the existing facilities, taking into account the physical layout of the plant and the delivered cost and availability of the particular chemical. As it has been established that raw sewage characteristics vary from municipality to municipality, the need for a treatability study at each plant is evident. In some cases it may be sufficient to accurately predict the most suitable chemical for a particular plant on the basis of jar testing studies alone.

PROCEDURES

Initial work consists of preliminary jar tests to establish the prime precipitant (iron, aluminum, or calcium salts) that will consistently provide the degree of phosphorus removal required. The jar testing should cover the equivalent of three, one-week periods of intensive testing using each of the chemicals throughout the day and in the various days of the week. Analyses should be conducted on raw samples and the supernatants from the jars. Through the use of probability plots, comparative chemical dosages and costs can be obtained. This information in conjunction with an assessment of the visual and analytic data obtained during the study and a knowledge of the existing plant facilities can provide a base for predicting the most suitable chemical.

An interim study report should be prepared and submitted based on the jar tests and include sufficient data to substantiate the conclusions reached. This report may also include a recommendation for a full scale pilot study using the most efficient chemical. Such a recommendation should be contingent upon a site evaluation to determine if existing facilities can be readily used for phosphorus removal in the manner which is proposed.

When the interim study report is reviewed and approved, a full scale pilot study may be carried out. The study can frequently be run on a portion of the plant and produce results equivalent to the complete plant at substantial savings. Prior to commencing the full scale study, the various points of chemical application should be assessed to ensure that adequate mixing capability is present in the existing plant. Mixing may be obtained through chemical discharge into the suction side of pumps, in an aerated grit chamber, into interconnecting channels or into the aeration tank. In most cases it will not be necessary to utilize flash mixers.

If full scale tests are to be conducted, it is expected that the studies would be of approximately six weeks duration for a primary treatment plant. For a secondary treatment plant, eight weeks of full scale operation should yield the required information. Following completion of the full scale studies, a complete treatability study report is to be prepared, documenting problems encountered at the plant, confirming the chemical to be used in permanent operation and containing recommendations for the implementation of phosphorus removal.

Phase I - Jar Testing

The use of jar testing procedures to simulate water treatment plant conditions is a well known and often used technique (1). More recently this same jar test procedure has been used to provide preliminary design information on phosphorus removal by chemical precipitation in municipal wastewater treatment systems. Tests are carried out on grab samples of either the raw sewage or final effluent. For primary plants, varying dosages of aluminum salts, iron salts and lime are added to raw sewage samples. Tests on biological treatment units are carried out using aluminum and iron salts applied to the final effluent which produces results similar to those obtained from chemical application to the mixed liquor. When primary and biological units are in operation both of the aforementioned tests are carried out.

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(1) Simplified Procedures for Water Examination. AWWA Manual, M12, p.42.

The procedure, which parallels that used by the potable water treatment plant operators (1), is described as follows:

1. Adopt a jar test procedure which must be continued throughout the test program at the plant. Use a standard arbitrary timing sequence ensuring adequate mixing and reaction time, [e.g., 5-minute fast mix (100 rpm) followed by 15-minute slow mix (25 rpm), settle for 30 minutes and sample supernatant].
2. Take a seven-litre grab sample of the waste stream to be tested.
3. Retain a well mixed one-litre raw sample of the above for measurement of total phosphorus and pH. Occasionally check soluble phosphorus, suspended solids and BOD (see Step 8).
4. Fill six one-litre beakers and place them under the multiple stirring apparatus.
5. Dose beakers two to six with varying dosages of the chemical selected, covering the initial range listed in Table A-1. Beaker No. 1 is a control and receives no chemical.

   Add the selected chemical dosages to each beaker in succession while running the mixer at 100 rpm. It is important that the chemicals be added as rapidly as possible. Continue to operate at this high speed after the last chemical addition to provide the required fast mixing time.

6. Adjust the mixer speed to slow mix in accordance with the procedure adopted in Step 1 and allow to run for the required slow mixing time.
7. During the slow mix and subsequent settling period record the following visual observations:
    - a comment on the time required for flocculation to take place, (slow, fast, etc.);
    - floc size after flocculation time, (small, medium, large);
    - floc settling characteristics, (slow to fast);
    - supernatant quality, (turbid to clear);
    - volume of sludge produced.
8. Analyze the well mixed raw sample and each of the jar supernatants, including the control sample, for total phosphorus and pH. Occasionally check soluble phosphorus, suspended solids and BOD on samples; generally each of these additional analyses should not exceed 10% of the number of total phosphorus analyses carried out.
9. Repeat Steps 2 to 8 ignoring Table A-1, using fresh samples of wastewater to narrow down the range of chemical dosages used. The rationale for choosing subsequent dosages involves attempting to bracket the range of removal efficiency or effluent quality required by selecting one dosage lower than the objective, one near the objective and one higher than the objective, (i.e., if the initial tests using alum, ferric chloride and lime showed phosphorus removals as listed in Table A-2, the indicated changes would be made in subsequent tests). At the present time the objective is either 80% removal or 1 mg/l effluent total phosphorus depending upon the particular drainage basin into which the plant discharges. This has been discussed previously.

TABLE A-1

Chemical		Dosage Ranges (mg/l)
Common Name	Chemical Formula	
Alum	$Al_2(SO_4)_3 . 14H_2O$	75 - 300
Ferric Chloride	$FeCl_3$	5 - 30*
Lime	$Ca(OH)_2$	75 - 300

* as Fe^{+++}

TABLE A-2

Chemical	Dosage (mg/l)	Total P Removal (%)	Total P in Jar Supernatant (mg/l)	Dosages to be used in Subsequent Tests (mg/l)
Alum	100	45	2.5	150
	150	70	1.5	150
	200	85	1.0	200
	250	95	0.8	250
	300	98	0.8	
Ferric Chloride	5*	78	1.3	4*
	10*	89	1.0	7*
	15*	95	0.8	10*
	20*	97	0.8	
	25*	98	0.8	
Lime	100	30	3.5	
	150	65	1.7	
	200	73	1.4	200
	250	84	1.1	250
	300	87	1.0	300

* as Fe^{+++}

It is essential that the jar tests be carried out over an extended period of time, preferably of three weeks duration, in order that a wide and representative variety of sewage characteristics are encountered. Grab samples should be taken at different times of the day and on various days of the week. Once the range of chemical dosages has been established, do not alter these dosages unless the results show that you are consistently underdosing or overdosing. In order to have sufficient data to draw meaningful conclusions, it is essential that a minimum of ten data points are obtained at each chemical dosage on each waste stream being studied.*

Statistical plots of the data obtained are used to determine the relative chemical dosages. Although in full scale operation the effectiveness of phosphorus removal is determined on the basis of average plant operating results, for purposes of evaluating jar test data, comparable chemical dosages are obtained at the 80% confidence level on probability curves.*

Data Analyses

Rather than looking at the average total phosphorus removal for each set of data, more meaningful information can be gained by plotting each set of ten points on arithmetic or log probability paper. This can be done by arranging the data in numerical order of percentage total phosphorus removal from raw sample or supernatant (effluent) total phosphorus concentration. The plot percentage total P removal or effluent total P concentration on the ordinate versus $\frac{x}{n+1}$ on the abscissa

where: n = total number of samples

x = sample number, e.g., 1, 2, 3, 4, etc.

When all data are thus plotted a direct comparison can be drawn between the various chemical dosages used. Use a separate graph for plotting the various removal results for each chemical on a particular waste stream. Two significant aspects of these curves should be considered:

---

* Edited to reflect integration of this Appendix (A) with total report.

1. The relative vertical position of the plot lines indicates the degree of effectiveness of the precipitant used at that given dosage.
2. The slope of the plot line indicates the degree of certainty of reliability of the chemical in achieving the required results.

From this analytical data, the relative economics of the various chemical processes for phosphorus removal can be determined on the basis of optimum dosage, delivered cost, and availability of the chemicals.

These data should form part of the interim study report to be completed prior to initiating full scale studies.

Phase II - Full Scale Pilot Studies

The results of the preliminary jar tests conducted as Phase I of the treatability studies for phosphorus removal will yield a conclusion as to the optimum chemical to be used for phosphorus removal at the particular wastewater treatment plant. Full scale studies can then be conducted using this prime coagulant to yield information in the following areas:

- confirm the chemical dosage;
- optimize the point of application;
- prove the suitability of plant hydraulics;
- prove that existing mechanical equipment will operate satisfactorily under the new service conditions;
- provide data on sludge characteristics;
- indicate the actual final effluent quality that will be attained;
- provide total annual operating costs related to phosphorus removal.

In some special cases, full scale studies may not be required or even warranted. Previous experience, accumulated technical information, and plant mechanical and process status could all combine to make full scale studies unnecessary.

If full scale tests are to be conducted, it is expected that the studies would be of approximately six weeks duration for a primary treatment plant. For a secondary wastewater treatment plant, eight weeks of full scale operation should yield the required information. Such a study would only involve chemical addition into the waste stream indicated most promising by the jar tests, assuming that addition at this point yielded satisfactory results. Subsequent work in altering the point of application to reduce chemical dosage can be conducted after the full scale facility is on stream permanently.

An assessment of digester operation during these studies is not considered essential. Flexibility in design of permanent facilities is obviously required.

Under certain circumstances an extended study beyond the time periods previously outlined may be required. The presence of a significant industrial waste load, e.g., cannery wastes, could necessitate more extensive studies both in the jar testing and full scale pilot work.

The prime objective of the full scale temporary phosphorus removal studies is to demonstrate the feasibility of effecting phosphorus removal at a particular installation without necessitating extensive plant modifications or additions. Some of the mechanical plant aspects that may be affected by phosphorus removal are:

- raw sludge collection and handling capability;
- return sludge pumping capacity;
- digester heat exchange capacity.

Essentially, the full scale studies should demonstrate that phosphorus removal, using the prime coagulant indicated by the jar tests, is compatible with the existing wastewater treatment processes.

While effecting phosphorus removal is the prime objective, the study should not be carried out in a manner which might lead to a deterioration in plant effluent quality.

In order to assess plant performance during the study period, an appreciable sampling and analytical work load will result. Under routine conditions it is expected that composite sampling of liquid sewage streams will be conducted a maximum of three times per week. These samples would be analyzed for total phosphorus, soluble phosphorus, BOD, pH, and suspended solids. Grab samples of various sludge streams will be taken several times a week. Expenditures eligible for reimbursement are only those covering analytical work conducted in addition to normal plant operation analyses.

During a secondary treatment plant study, it is expected that approximately 130-man hours of laboratory services would be required to handle the necessary analyses; for a primary plant, the manpower requirements for laboratory analyses are estimated at 90-man hours.

The normal in-plant monitoring required for plant operation should be sufficient to yield the necessary information on the effects of implementing phosphorus removal at the existing wastewater treatment plant. However, if normal in-plant tests are minimal, it is suggested that the following observations be conducted during the study: sludge levels in clarifiers, dissolved oxygen concentrations in aeration tanks, sludge volume index values, and return sludge rates.

A previous outline entitled, "Guidelines for Initiating Treatability Studies for Phosphorus Removal" contained applications and instructions for rebate of treatability study costs. It was pointed out that treatability study equipment purchased specifically for such a study would revert to the Crown if reimbursement for such material was made. In this regard, it is advisable for the operating authority to directly purchase such items as chemical storage tanks and feed pumps suitably sized for use in the permanent facilities; such equipment could then be incorporated into the permanent treatment facility as part of the regular capital costs. Where lime is selected as the prime coagulant the Ministry will provide, on loan, a package lime feed system for the duration of the full scale study. Although the use of temporary "swimming pool" type storage tanks is an expedient measure, they have proven unreliable, resulting in uncontrolled spills and the loss of large volumes of chemical.

The manpower costs, exclusive of analytical work, associated with the full scale studies will arise from three major areas:

- initial plant inspection and equipment set up;
- technical support for the duration of the study;
- sampling and on site analyses conducted during the study.

During these studies, technical assistance is available, if required, from the Ministry of the Environment, Research Branch. Having conducted many full scale phosphorus removal studies, staff can provide information both during initial plant set up and in assessing operating problems that may occur during the study. In any case, if operating problems are encountered during a phosphorus removal study, it is essential that the Phosphorus Program Co-ordinator be made aware of the nature of these difficulties. Such contact should ensure that proper operating conditions are being effected during these studies.

The final treatability study report should document the full scale studies and contain appropriate recommendations to implement phosphorus removal on a permanent basis without deterioration in existing plant processes. The report must include total annual operating cost estimates for phosphorus removal and the appropriate cost breakdown.

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Canada.

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Phosphorus Program Co-ordinator

Contributions from the Research, Project Operations and Sanitary Engineering Branches are gratefully acknowledged.

APPENDIX B

SUMMARY OF JAR TEST AND FULL SCALE PHOSPHORUS REMOVAL TREATABILITY DATA

TABLE B-1 SUMMARY OF JAR TEST AND FULL SCALE PHOSPHORUS REMOVAL TREATABILITY DATA

PLANT	STUDY	PLANT TYPE	JAR TESTS[1],[2]									FULL SCALE[1],[3]									
			DATE	AVG TP		FE DOSE		AL DOSE		CA DOSE		DATE	FLOW	AVG INFL TP	AVG EFFL TP	CHEM	DOSE	PT OF ADD	CLARIFIER O/F RATE (gpd/ft^2)	COST[4] ($/MIG)	REMARKS
				RAW	SEC	RAW	SEC	RAW	SEC	RAW	SEC										
Amnerstburg Anderdon & Malden	45	Primary	5/72	5.6		20.0		13.6		81		2/74	0.85	4.8	1.2	FE	20.0	R	223.	33.9+	2nd Study-Lime in Raw, 185 mg/l Avg P out=1.4, clarifier OF=223
Beileville	69	Conv. Actd. Sludge	5/73	7.0	2.5	15.0	12.0	12.0	5.0	160											
Bolton	25	Conv. Actd. Sludge	12/72	10.7	7.7	32.0	24.0	25.0	13.5	393		8/73	0.20	6.2	0.24	AL	11.0	M	654	35.7-	
Brantford	1	Conv. Actd. Sludge	8/72	6.3	4.1	33.0	20.0	18.1	11.0	270		3/73	10.0	5.5	1.2	FE	8.8	M	650	14.5+	2nd Study-Pickle Liquor in mixed liquor, 10 mg/l FE, Avg. P in=6.6, Avg P out=1.1
Brockville	82	Conv. Actd. Sludge	8/74	3.0		13.5		6.4		81											
Burlington Drury Lane	20	Conv. Actd. Sludge	3/72	4.9	4.1		28.0	20.0	15.0	216	30										Wastewater Technology Centre Study
Burlington Drury Lane No. 2	79	Conv. Actd. Sludge	3/75	4.7	3.0	19.0	9.5	11.0	5.5	171											
Burlington Skyway	48	Conv. Actd. Sludge	6/71	8.4		20.0		13.7		95											

[1] All phosphorus and chemical dosage values are in mg/l.
[2] Jar test chemical dosages are those required to achieve 1 mg/l of total phosphorus 80% of the time.
[3] Full scale dosages are averages over the study period.
[4] + sign = cost to achieve 1 mg/l TP effluent objective is greater than indicated.
- sign = cost to achieve 1 mg/l TP effluent objective is lower than indicated.

M = Mixed liquor.
R = Raw wastewater.
Flow as mgd.

TABLE B-1 Continued

PLANT	STUDY	PLANT TYPE	JAR TESTS[1],[2]									FULL SCALE[1],[3]									
			DATE	AVG TP		FE DOSE		AL DOSE		CA DOSE		DATE	FLOW	AVG INFL TP	AVG EFFL TP	CHEM	DOSE	PT OF ADD	CLARIFIER O/F RATE (gpd/ft^2)	COST[4] ($/MIG)	REMARKS
				RAW	SEC	RAW	SEC	RAW	SEC	RAW	SEC										
Caledonia	28	Conv. Actd. Sludge	12/72	9.9	5.2	45.0	14.0	40.0	15.0			1/74	0.17	5.9	1.1	CA	105	R	361	22.3+	
Campbellford	54	Conv. Actd. Sludge	9/73	1.7	0.6	5.0		2.3		76											
Cayuga	2	Ext. Aeratn.	11/72		3.8		20.0		12.0			7/73	0.16	6.9	0.5	FE	12.5	M	354	20.7-	
Cambridge Hespeler	43	Hi-Rate Actd. Sludge	5/73		4.7		18.0		15.9												
CFB Borden	36	Primary	9/71	4.8		18.0		12.0		216		5/74	1.1	3.4	0.6	CA	135	R	156	30.0-	Wastewater Technology Centre Study
CFS Gloucester	30	Conv. Actd. Sludge	11/71	6.4	4.6	30.0	17.0	19.0	5.0	150	108										Wastewater Technology Centre Study
CFB Petawawa	37	Primary	10/71	8.9		45.0		25.0				3/73	0.97	5.9	1.1	AL	10.0	R	440	28.6+	Wastewater Technology Centre Study
CFS Trenton	38	Conv. Actd. Sludge	11/71		3.2		15.0		7.0			11/73	1.2	2.5	0.4	AL	3.0	M	740	5.9-	Wastewater Technology Centre Study
CFB Uplands	35	Conv. Actd. Sludge	10/71	6.8	4.5	40.0	25.0	22.0	22.0			4/74	0.65	3.0	1.0	AL	17.5	R	600	50.1	Wastewater Technology Centre Study
Clarkson	83	Ext. Aeratn.	9/74		4.3		14.0		7.0												
Coburg	85	Conv. Actd. Sludge	10/74	4.5	1.0	20.0	4.0	10.5	2.0	144											
Crystal Beach	23	Conv. Actd. Sludge	8/72	2.0	2.2	8.0	6.0	4.5	2.3	97		11/72	0.57	4.4	1.5	AL	2.1	R	730	7.2+	

TABLE B-1 Continued

PLANT	STUDY	PLANT TYPE	JAR TESTS^{1,2}									FULL SCALE^{1,3}									
			DATE	AVG TP		FE DOSE		AL DOSE		CA DOSE		DATE	FLOW	AVG INFL TP	AVG EFFL TP	CHEM	DOSE	PT OF ADD	CLARIFIER O/F RATE (gpd/ft^2)	COST^4 ($/MIG)	REMARKS
				RAW	SEC	RAW	SEC	RAW	SEC	RAW	SEC										
Delhi	57	Conv. Actd. Sludge	10/73	5.3	4.2	16.5	13.5	12.0	7.5	222		2/74	0.47	4.9	1.2	FE	4.5	M	375	7.4+	
Duffin Creek	81	Conv. Actd. Sludge	2/75	4.8	3.1	15.0	9.0	11.8	5.3	154											
Dundas	67	Conv. Actd. Sludge										11/73	1.5	5.5	0.9	AL	5.5	M	400	18.8-	
Dunnville	22	Ext. Aeratn.	7/72		5.2		9.0		5.0			3/73	1.5	4.9	1.1	P	8.2	M	450	13.6+	Jar Test - Pickle liquor in secondary required 10 mg/l FE. Full scale price is for $FeCl_3$
Elora	3	Ext. Aeratn.	7/72		4.2		26.0		10.0			4/73	0.17	7.2	0.8	FE	16.7	R	545	27.6-	
Elmira	49	Conv. Actd. Sludge	7/71	10.9	4.1	30.0	17.0	22.7	11.4	216		6/74	0.73	4.5	1.3	FE	7.0	M	230	10.0+	
Fergus	4	Conv. Actd. Sludge	6/72	5.4	2.9	22.0	15.0	13.0	6.8	95		4/73	0.4	5.4	0.9	FE	7.4	M	327	12.2-	
Fort Erie	75	Conv. Actd. Sludge	8/74	4.0		9.0		7.5		107		12/74	1.92	4.6	1.3	FE	10.2	R	480	18.2	
Frenchman Bay	87	Conv. Actd. Sludge	1/75	4.9	3.9	17.0	15.0	9.5	5.5												
Galt	5	Conv. Actd. Sludge	8/72	8.0	3.4	45.0	25.0	36.0	12.0	298											
Georgetown	78	Conv. Actd. Sludge	3/75	5.0	2.6	13.0	10.5	9.0	10.0												

TABLE B-1 Continued

PLANT	STUDY	PLANT TYPE	JAR TESTS[1],[2]									FULL SCALE[1],[3]									
			DATE	AVG TP		FE DOSE		AL DOSE		CA DOSE		DATE	FLOW	AVG INFL TP	AVG EFFL TP	CHEM	DOSE	PT OF ADD	CLARIFIER O/F RATE (gpd/ft^2)	COST[4] (S/MIG)	REMARKS
				RAW	SEC	RAW	SEC	RAW	SEC	RAW	SEC										
Grand Valley	55	Ext. Aeratn.	8/73			6.6		30.0		10.0											
Guelph	26	Conv. Actd. Sludge	1/73	3.7	4.1	15.0	18.3	6.8	9.1	162		1/73	1.5	6.1	0.8	AL	9.1	M	411	31.6+	Activated silica added at 4 mg/l throughout most of study
Hagersville	77	Conv. Actd. Sludge										2/74	0.49	4.8	1.7	AL	6.8	M	1203	23.2+	
Hamilton	29	Conv. Actd. Sludge	7/73	3.3		3.7		2.4		42											Wastewater Technology Centre Study
Kingston	76	Primary	7/74	4.9		16.0		8.0		120											
Kitchener	6	Conv. Act. Sludge	5/72	10.0	5.9	52.0	22.0	27.0	9.0	271		4/73	14.6	9.2	1.0	AL	8.5	M	727	29.9	
Leamington	21	Primary	6/72	4.5		15.0		11.4		81		8/72	2.2	3.6	1.7	FE	20.0	R	560	33.1+	
Lindsay	72	Stabilization Pond	8/74	6.9		40.0		13.0													
London Adelaide	40	Conv. Actd. Sludge	5/72	7.8	5.6	25.0	30.0	25.0	25.0	95	149										
London Greenway	61	Conv. Actd. Sludge	7/72	8.0	2.0	40.0	3.0	19.0	4.0	330		3/73	4.9	2.0	0.8	FE	3.0	M	502	5.0-	
London Oxford	39	Conv. Actd. Sludge	5/72	7.6	7.4	30.0	30.0	15.9	15.9	122	149										
London Pottersburg	42	Conv. Actd. Sludge	5/72	8.3	5.4	25.0	25.0	20.4	15.9	122	95										
London Vauxhall	41	Conv. Actd. Sludge	5/72	6.4	5.4	30.0	25.0	25.0	25.0	122	122										

TABLE B-1 Continued

PLANT	STUDY	PLANT TYPE	JAR TESTS[1],[2]									FULL SCALE[1],[3]									
			DATE	AVG TP		FE DOSE		AL DOSE		CA DOSE		DATE	FLOW	AVG INFL TP	AVG EFFL TP	CHEM	DOSE	PT OF ADD	CLARIFIER O/F RATE (gpd/ft^2)	COST[4] ($/MIG)	REMARKS
				RAW	SEC	RAW	SEC	RAW	SEC	RAW	SEC										
Markham John Street	88	Conv. Actd. Sludge	1/75	7.0	5.2	35.0	28.0	25.0	15.0	214											
Mississauga Lakeview	84	Conv. Actd. Sludge	10/74	10.3	2.0	24.0	10.0	15.5	5.7	135											
Moore TWP Corunna	27	Ext. Aeratn.	10/72				30+ 62 Ca					7/73	0.25	11.8	0.87	FE + CA	25 + 51	M	500	53.4-	
Napanee	24	Conv. Actd. Sludge	7/72	4.2		12.0		13.0		108											
Niagara Falls	74	Primary	7/74	5.1		12.0		8.0		135		1/75	6.96	5.7	1.6	FE	14.3	R	418	25.3+	
North Toronto	62	Conv. Actd. Sludge	1/72									1/72	8.5	5.5	0.9	FE	12.0	R	403	19.7-	
Oakville South West	70	Conv. Actd. Sludge	8/73	12.5	7.1	25.0	10.0	14.0	9.0	135		1/75	3.5	6.2	1.8	FE	14.1	M	555	22.6+	
Oakville South East	86	Conv. Actd. Sludge	11/74	5.9	6.5	18.5	17.0	9.0	8.0	107		3/75	1.33	6.1	1.4	FE	11.6	M	371	18.6+	
Oshawa Harmony Creek	93	Trickling Filter Primary	3/75	5.5 6.1	3.1	13.0 15.0	11.0	11.8 13.6	6.4	76 103											
Paris	7	Extd. Aeratn.	8/72		3.9		35.0		14.0			5/73	0.38	5.7	0.9	AL	9.4	M	293	310-	
Parry Sound	53	Primary	8/73	12.1		45.0		28.0		163											
Port Colborne East	63	Ext. Aeratn.	10/73		2.5		8.0		4.0			9/74	1.33	3.7	0.6	AL	2.5	M	940	7.6-	

TABLE B-1 Continued

PLANT	STUDY	PLANT TYPE	JAR TESTS^{1,2}									FULL SCALE^{1,3}									
			DATE	AVG TP		FE DOSE		AL DOSE		CA DOSE		DATE	FLOW	AVG INFL TP	AVG EFFL TP	CHEM	DOSE	PT OF ADD	CLARIFIER O/F RATE (gpd/ft^2)	COST^4 ($/MIG)	REMARKS
				RAW	SEC	RAW	SEC	RAW	SEC	RAW	SEC										
Port Colborne West	64	Conv. Actd. Sludge	10/73	2.7	2.1	7.0	6.0	8.0	3.0	107		8/74	1.10	2.3	0.5	AL	3.0	M	510	9.1	2nd Study - $FeCl_3$ in mixed liquor 2.0 mg/l Fe, Avg P in=3.6, Avg P out=0.5
Port Dalhousie	73	Primary	7/74	4.3		12.0		9.0		125											
Port Dover	8	Primary	8/72	6.4		40.0		20.0		325		7/73	0.46	5.6	0.6	FE	18.5	R	136	30.8-	
Port Hope	71	Conv. Actd. Sludge	3/74	5.2	3.3	25.0	20.0	16.0	11.0												
Preston	9	Conv. Actd. Sludge	10/72	12.2	5.2	70.0	33.0	41.0	25.0	325		4/73	2.5	8.1	0.7	FE	11.0	M	640	18.2-	
Richmond Hill	80	Conv. Actd. Sludge	3/75	5.9	3.3	12.5	7.5	7.5	4.0												
Sidney TWP Batawa	10	Conv. Actd. Sludge	10/72	3.1	2.0	12.0	6.0	6.0	3.0	108		5/73	0.21	2.9	0.6	AL	3.5	M	875	12.3-	
Simcoe	11	Conv. Actd. Sludge	10/72	10.6	5.3	50.0	28.0	27.0	14.0	216		7/73	1.6	8.4	0.9	AL	9.2	M	503	31.9-	
St. Catharines Port Weller	65	Conv. Actd. Sludge	10/73	5.9	2.9	15.0	10.0	10.0	5.0	143		10/74	6.3	7.0	0.8	AL	4.0	M	438	11.6-	
St. Marys	56	Conv. Actd. Sludge	9/72	5.3	3.9	28.0	22.0	23.0	12.7	300											
St. Thomas	59	Conv. Actd. Sludge	3/72	10.0		13.0		4.5													

TABLE B-1 Continued

PLANT	STUDY	PLANT TYPE	JAR TESTS[1],[2]									FULL SCALE[1],[3]									
			DATE	AVG TP		FE DOSE		AL DOSE		CA DOSE		DATE	FLOW	AVG INFL TP	AVG EFFL TP	CHEM	DOSE	PT OF ADD	CLARIFIER O/F RATE (gpd/ft^2)	COST[4] ($/MIG)	REMARKS
				RAW	SEC	RAW	SEC	RAW	SEC	RAW	SEC										
Stouffville	91	Conv. Actd. Sludge	1/75	6.1	3.4	20.0	13.0	15.0	7.0	143											
Tillsonburg	12	Conv. Actd. Sludge	8/72	10.5	6.9	50.0	37.0	27.0	14.0	325		4/73	0.8	8.5	0.3	AL	12.5	M	235	43.4-	
Toronto Main	50	Conv. Actd. Sludge	3/73	3.8		12.0		14.0													
Toronto Highland Creek	51	Conv. Actd. Sludge	3/73	6.4		17.0		10.0		135											
Toronto Humber	52	Conv. Actd. Sludge	3/73	2.3		10.5		5.0	5.0	108											
Trenton	13	Primary	6/72	8.2		35.0		22.7		189											
Unionville	90	Conv. Actd. Sludge	1/75	9.0	5.5	30.0	22.0	30.0	13.0	214											
Vaughan TWP West Don	89	Conv. Actd. Sludge	1/75	10.5	3.0	12.0	20.0	50.0	17.0	237											
Wallaceburg	14	Conv. Actd. Sludge	8/72	11.3	6.6	21.0	22.0	15.0	9.1	108		6/73	0.5	4.4	1.0	CA	114	R	312	24.2	
Waterdown	18	Conv. Actd. Sludge	3/72	6.6	6.7	55.0	50.0	25.0	31.0	162	216	1/72	0.10	7.1	1.4	AL	18	M	200		Wastewater Technology Centre Study
Waterford	15	Lagoon	10/72	4.3		25.0		13.6													
Waterloo	16	Conv. Actd. Sludge	7/72	7.2	2.1	28.0	13.0	15.4	6.4	176		4/74	6.9	5.3	0.5	FE	6.5	M	531	10.7-	Clarifier OF Rate 2 clarifiers = 1040 3 clarifiers = 531

TABLE B-1 Continued

PLANT	STUDY	PLANT TYPE	JAR TESTS[1],[2]									FULL SCALE[1],[3]									
			DATE	AVG TP		FE DOSE		AL DOSE		CA DOSE		DATE	FLOW	AVG INFL TP	AVG EFFL TP	CHEM	DOSE	PT OF ADD	CLARIFIER O/F RATE (gpd/ft^2)	COST[4] ($/MIG)	REMARKS
				RAW	SEC	RAW	SEC	RAW	SEC	RAW	SEC										
Westminster TWP	17	Extd. Aeratn.	9/72		5.1		18.0		11.4			9/73	0.46	8.7	0.3	P	9.0	M	912	15.3	2nd Study - $FeCl_3$ in mixed liquor 9 mg/l Fe, Avg P in=7.9, Avg P out=0.6 clarifier OF rate = 173
Whitby Corbett Creek	92	Conv. Actd. Sludge	1/75	2.8	1.0	14.0	2.0	7.7	1.0												
Whitby Pringle Creek	66	Conv. Actd. Sludge	1/73	6.0	4.2	20.0	14.0	18.0	9.0	81		11/73	0.9	5.8	0.7	FE	8.0	M	173	13.1	
Windsor Little River	46	Conv. Actd. Sludge	6/72	4.4		20.0		13.6		81		3/72	3.0	9.9	1.2	AL	13.6	R	300	50.9+	
Windsor West	47	Primary	3/72	5.4		20.0		9.1		81		7/72	21.7	7.8	1.0	AL	8.2	R	480	30.7	
Woodstock	58	Conv. Actd. Sludge	7/72	4.0	3.3	30.0	25.0	17.5	14.0	250		8/73	5.1	8.0	0.2	FE	17.0	M	655	28.1-	
Woolwich TWP St. Jacobs	44	Extd. Aeratn.	3/73		1.8		10.0		4.5			2/74	0.14	5.5	0.47	AL	2.3	M	286	8.1	

APPENDIX C

DERIVATION OF THE RELATIONSHIP BETWEEN JAR TEST PREDICTIONS AND FULL SCALE CHEMICAL REQUIREMENTS

TABLE C-1 COMPARISON OF JAR TEST AND FULL SCALE CHEMICAL DOSAGES

Study	Chem.	Jar Test Dosage		Full Scale Average Dosage	Jar Test:Full Scale	
		80%	50%		80%	50%
25	Al	13.5	11.0	11.0	1.23	1.00
1	Fe	20.0	12.0	8.8	2.27	1.36
38	Al	7.0	5.5	3.0	2.23	1.83
57	Fe	13.5	11.0	4.5	3.00	2.44
49	Fe	17.0	10.5	7.0	2.43	1.50
4	Fe	15.0	10.0	7.4	2.03	1.35
26	Al	9.1	8.0	9.1	1.00	.88
6	Al	9.0	8.0	8.5	1.05	.94
61	Fe	3.0	3.0	3.0	1.00	1.00
70	Fe	10.0	4.5	14.1	.71	.32
86	Fe	17.0	14.0	11.6	1.47	1.21
64	Al	3.0	2.5	3.0	1.00	.83
9	Fe	33.0	25.0	11.0	3.00	2.27
10	Al	3.0	2.0	3.5	.86	.57
11	Al	14.0	8.0	9.2	1.52	.87
65	Al	5.0	4.0	4.0	1.25	1.00
12	Al	14.0	12.0	12.5	1.12	.96
18	Al	31.0	17.0	18.0	1.72	.94
16	Fe	13.0	4.5	6.5	2.00	.69
66	Fe	14.0	10.0	8.0	1.75	1.25
58	Fe	25.0	15.0	17.0	1.47	.88
2*	Fe	20.0	15.0	12.5	1.60	1.20
22*	Fe	9.0	8.0	8.2	1.10	.90
63*	Al	4.0	2.5	2.5	1.60	1.00
17*	Fe	18.0	13.0	9.0	2.00	1.44
44*	Al	4.5	3.5	2.3	1.96	1.52
7*	Al	14.0	9.0	9.4	1.49	.96
				Average Ratio	1.63	1.15

* Extended aeration plant (all others conventional activated sludge plants).

1. Ratio of jar test/full scale dosages:

   a) Ferric chloride and alum data combined (n=27)

   Average ratio of $\frac{\text{Jar Test (80\%)}}{\text{Full Scale Average}}$ = 1.63

   Average ratio of $\frac{\text{Jar Test (50\%)}}{\text{Full Scale Average}}$ = 1.15

   b) Ferric chloride data alone (n=14)

   Average ratio of $\frac{\text{Jar Test (50\%)}}{\text{Full Scale Average}}$ = 1.24

   c) Alum data alone (n=13)

   Average ratio of $\frac{\text{Jar Test (50\%)}}{\text{Full Scale Average}}$ = 1.06

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models for chemical phosphorus
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